Dead zone analysis of ECAL barrel modules under static and dynamic load

T.PIERRE-EMILE[a,*] and M.ANDUZE [a] on behalf of SiW ECAL ILD collaboration

[a] *Laboratory Leprince Ringuet (CNRS),*
École polytechnique, avenue Fresnel, 91 128 Palaiseau Cedex; France
E-mail: thomas.pierre-emile@llr.in2p3.fr

ABSTRACT:

In the context of ILD project, we started to study the impact of environmental loads on the Electromagnetic CALorimeter (ECAL) barrel detector. This ECAL barrel consists of several independent modules which are mounted on the Hadronic CALorimeter (HCAL) barrel itself mounted on the cryostat coil and the yoke. We need to estimate the gap required for ECAL modules assembly and operation to avoid mechanical contacts over the barrel lifetime. In the meantime, we need to minimize those gaps to reduce dead spaces and optimize detector hermiticity. The aim is to study the gap between ECAL barrel modules. To do so, we performed several FE static analysis with two different HCAL barrel designs. Moreover, because of the implantation site of the whole project in Japan, seismic analysis were carried out in addition to static ones. This article shows results of these analysis done with the FE method in ANSYS. First results show impact of HCAL design on the ECAL modules motion in static load. The second part dedicated to seismic approach on a larger model (including yoke and cryostat) gives additional results on earthquake consequences.

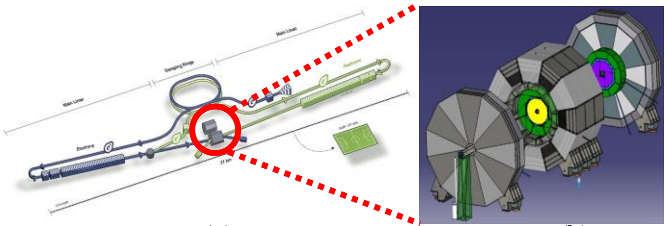
KEYWORDS: ILD, FEA, ANSYS, seismic, earthquake.

[*] Corresponding author.

Contents

1. Introduction

The International Large Detector (ILD) represents the conceptual design of a high performance detector [3] which should be a part of the International Linear Collider (ILC). This installation for high precision physics [1] will complete and push forward the analysis done at the Large Hadron Collider (LHC) in Geneva. Analysis carried at ILC will essentially involve electrons and positrons collisions at 500GeV [5] with the use of particle flow algorithm [2]. This detector is based on high granularity calorimeters as dense as possible (minimal dead zones) [4].



(a) *(b)*

Figure 1 : ILD within ILC: (a) picture of ILC installation; (b) ILD concept image from CAD file

Construction of this gigantic program in Japan requires a large amount of work. This report, dedicated to mechanics of the ECAL structure in it environment, represents only a small part of the work done and to be done.

2. ECAL barrel module: preliminary approach

2.1 ECAL barrel modules presentation:

This study focuses on the ECAL barrel relative motion according to its environment. The ECAL barrel is composed of 40 modules (eight staves of five modules). Each module is a trapezoidal alveolar structure made of tungsten embedded into carbon fiber composite. Every alveoli are filled with detection layers called slab. Thanks to rail systems, modules can be slide into the HCAL barrel (adjacent detector which hold the ECAL). Two kind of clearances (i.e. gap❶ and gap❷) can be defined to avoid module contacts over the detector lifetime

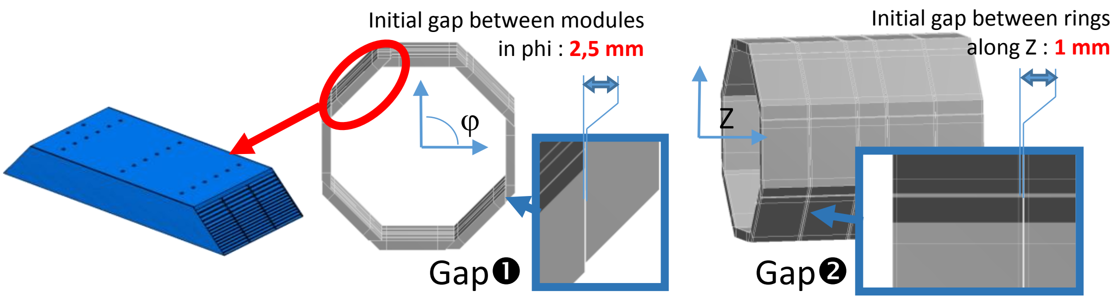


Figure 2: Picture of the ECAL barrel and clearances considered in the analysis

First part of this study consisted of modelling the ECAL module under its own weight.

2.2 ECAL geometry used for FEA:

Initially, shell model was used with ANSYS ACP. This method turned out to be time consuming for one module. Knowing that the ECAL barrel is made of 40 modules, solving time would increase dramatically with larger model. It has been decided to use a simplified model to deal with this. Shell elements are replaced by 3D solid ones with equivalent material to obtain the comparable results. The geometry is made of two stiff flanges and a rather soft core material

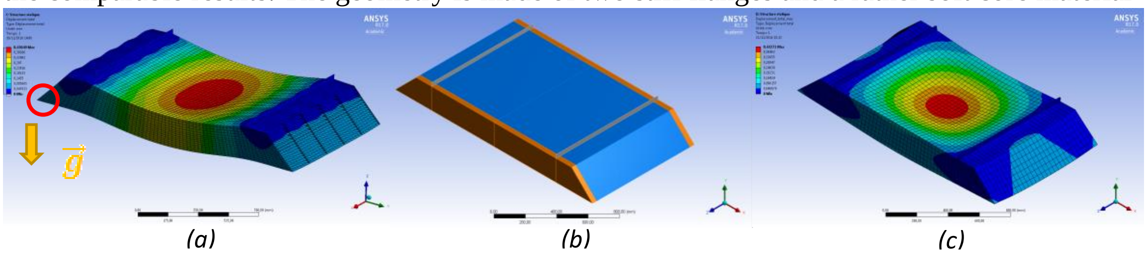
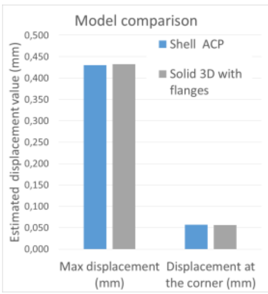
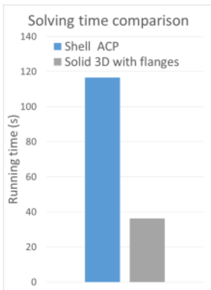


Figure 3: (a) Shell analysis of the 12 o'clock ECAL module under gravity; (b) simplified ECAL model with hard flanges and soft core; (c) 3D solid analysis of the 12 o'clock ECAL.

Thanks to this choice, similar results were obtained between (a) and (c) but solving time was considerably reduced (~70%). The following table and bar charts show this improvement.

Model	Max disp. (mm)	Disp. corner (mm)	Solving time (s)	Time saving (%)
Shell	0.430	0.057	116.642	N/A
Solid 3D	0.433	0.056	36.177	69.0





3. Static analysis: HCAL + ECAL:

3.1 Designs used:

For the purpose of this analysis, two HCAL designs were used, the Semi Digital Hadronic CALorimeter (**SDHCAL** design) and the Analog Hadronic CALorimeter (**AHCAL** design)

3.1.1 SDHCAL barrel:

The HCAL is also an alveolar based structure which hosts detection layers. The structure is mainly made of stainless steel plates which account for both weight and stiffness. The SDHCAL design (see next figure) is made of stainless steel layers called absorbers (15mm thick) reassembled by two side flanges (10 mm thick). Five wheels are stacked to produce the full barrel. Each wheel has the same width as the ECAL modules.

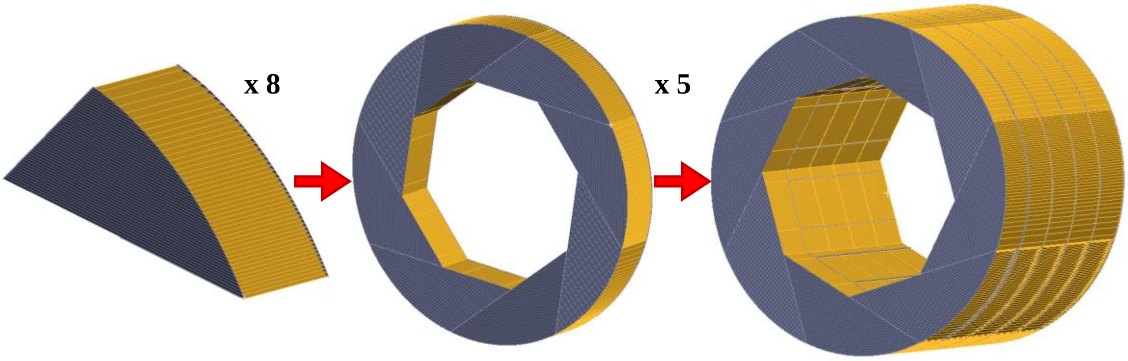


Figure 4: Sketch of SDHCAL individual module (left), ring (middle) and finally full barrel (right). Absorber 15mm thick in yellow and flanges 10mm thick in grey

This empty structure (i.e. without detection layers) represents a total mass of about 460t. Electronic and detection layers represents about 184t.

3.1.2 AHCAL barrel:

As for the SDHCAL, the AHCAL is an alternative hollow structure which hosts detection layers with a different insertion principle. Detection layers are slide in along the beam axis. This version of HCAL is based on 2 symmetrical modules which are duplicated to produce a wheel. Two wheels are needed to get the full barrel. Next picture gives an explanation.

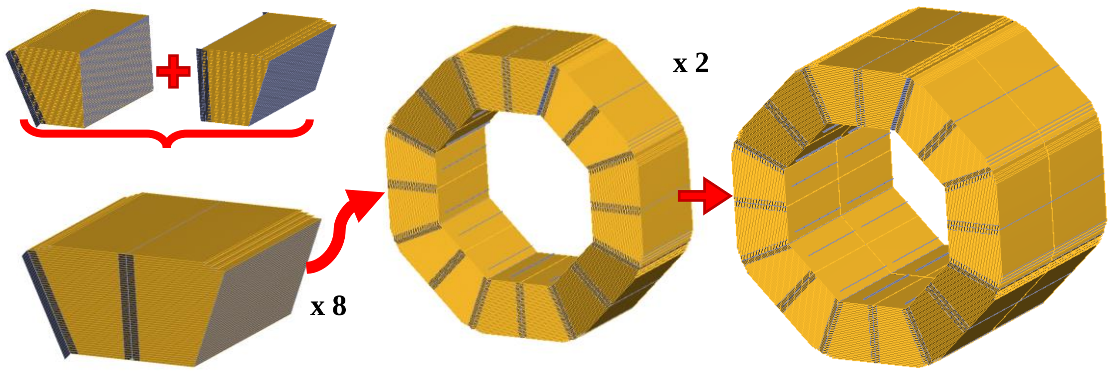


Figure 5: Sketch of AHCAL two symmetrical modules which produce a "super module" (left), ring (middle) and full barrel (right). Absorber 16mm thick in yellow and flanges in grey

With absorber thickness of 16mm the total mass for the HCAL barrel is of about 470t to which one can add approximately 142t for detection layers.

3.2 Boundary conditions and results:

For both designs the HCAL is supposed to be held at 3 and 9 o'clock. However kinematics is slightly different. The two coming sketches depict those differences.

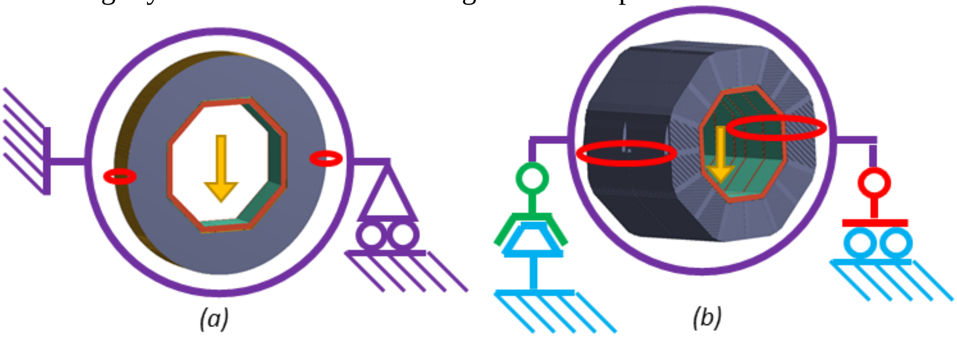


Figure 6: Mechanical linkage used as boundary conditions for (a) SDHCAL and (b) AHCAL

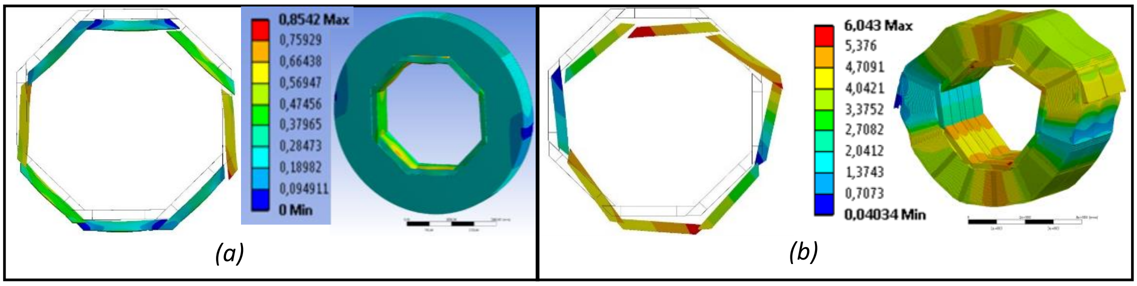


Figure 7: Displacement field obtained for SDHCAL (a) and AHCAL (b) designs under its own weight with electronic considered as point mass

For the SDHCAL, the maximum total displacement is 0.9mm. The smallest gap between ECAL modules in phi (gap➊) is reduced from 2.5mm to 2.31mm. On the other hand, total displacement for AHCAL is estimated to be 6mm with a reduction of gap➊ down to 0.95mm. Hence, the SDHCAL design is stiffer than the AHCAL which would help minimizing gap➊.

4. Earthquake analysis:

4.1 Context and Specifications used: ISO 3010:

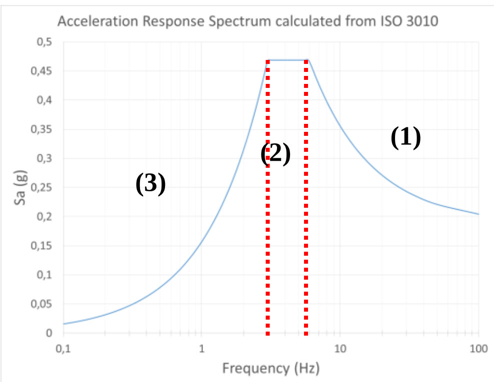


Figure 8 : Acceleration Response Spectrum at Kitakami site (ISO 3010)

This section focuses on preliminary studies of the structure response in case of earthquakes. The Kitakami site (in Japan) foreseen for ILD installation is known for its seismic activity. Response spectrum analysis was done on one design as a starting point. The AHCAL design was chosen as it revealed to be the least stiff.

Several specifications for civil engineering can be used. The EUROCODE 8 [6] and ISO 3010 [7] are one of them. This latter (ISO 3010) is used by Architectural Institute of Japan and therefore also used here. This method gives the against shown Acceleration response spectrum with a peak range between 3Hz and 7Hz

4.2 Design used and simplifications:

Generally, seismic data measurements are provided from the ground and structures analyzed must touch it. Nevertheless, several components separate the HCAL from the ground. It is mounted inside a cryostat itself inserted inside the central yoke supported by two air pads. Here, both air pads are supposed perfectly fixed to the ground. The cryogenic fluid and copper coil mass of the cryostat are not taken into account. Moreover, detection layers inside the HCAL and the yoke are not taken into account. This gives a total detector mass of about 3100t.

To be able to model this large assembly, new simplifications were done. Relative motion of fixations have been removed. Moreover, adjacent plates within the HCAL were merged and considered as one single thicker plate for seismic analysis.

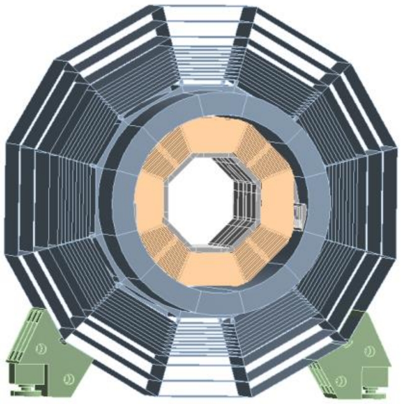


Figure 9: Full structure used for earthquake analysis: air pads (green); central yoke + cryostat (blue); AHCAL barrel (orange); ECAL barrel (grey)

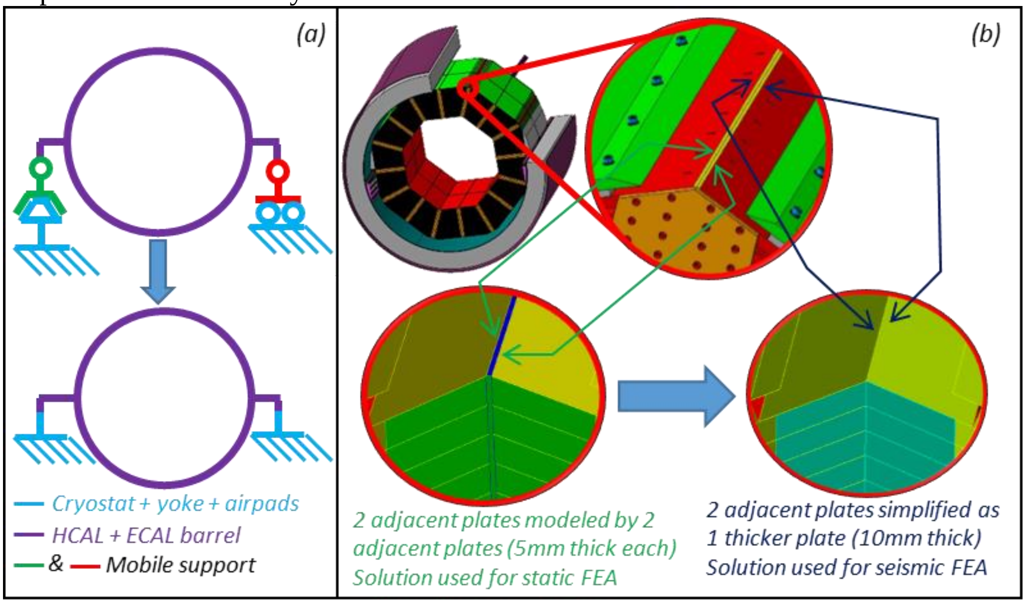


Figure 10: (a) Kinematic chain simplifications of the HCAL; (b) HCAL adjacent plates merging

Table 1: simplifications consequences on FEA estimates:

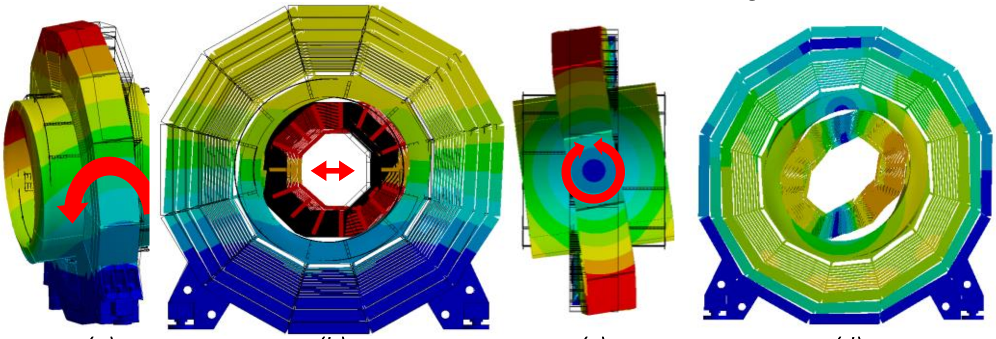
	Case1: Static FEA in section 3.2	**Case2 = Case1 without detection layers**	**Case3 = Case2 + changes (a) and (b) from (Figure 10)**	**Case4 = Case3 + cryostat + Yoke**
Total displ	6.04	5.04	4.09	5.62
Min gap ➊	0.95	1.27	1.31	1.98

One can clearly see that detection layers weight and simplifications made play an important role in the estimated results. Gap➊ value changes depending on cases. In case4 (used for seismic analysis) ECAL relative motion reduces. This might be due to the HCAL supports which are following the cryostat deformation. In other words, the ECAL tends to follow general motion thanks to the support and cryostat elasticity. The HCAL surrounding elements doesn’t seem to be infinitely rigid. Further studies might help in understanding these unexpected results.

4.3 Earthquake results and discussions:

4.3.1 Eigenvalue analysis:

Eigenvalues have been determined filtering the most participating modes between 0Hz and 50Hz. 42 modes were found. They account for about 90% of the total mass. 4 modes are isolated here because they have a significant proportion of mass involved which should drive the detector motion. This doesn't mean that other modes can be disregarded.



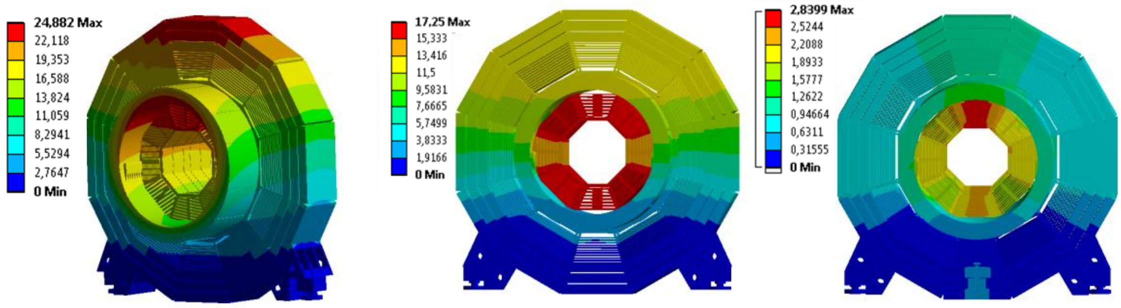
(a) (b) (c) (d)

Figure 11: (a) mode 1 at 2.3Hz; (b) mode 2 at 3.0Hz; (c) mode 6 at 7.0Hz; (d) mode 9 at 8.6Hz with 68%, 68%, 88% and 35% of mass involved respectively

Eigenvalues estimated for this cantilever structure are in the range of the earthquake peak (Figure 8). Low frequency values with significant amount of mass involved are found for horizontal ground motion whereas the structure is stiffer along the vertical direction. Therefore horizontal accelerations are foreseen to have a bigger impact than the vertical ones.

4.3.2 Displacement analysis:

Acceleration spectrum calculated from ISO3010 was used in 3 different directions. This first approach considers that ground acceleration is unidirectional (acceleration combination being harder to estimate). One also has to know that no recombination was done here. Only acceleration impact is studied (i.e. gravity is not considered).



(a) (b) (c)

Figure 12: without recombination (a) results for acceleration parallel to the beam pipe; (b) results for acceleration perpendicular to the beam pipe; (c) results for vertical acceleration

Acceleration parallel to the ground are the most damaging for the structure. The same set of analysis was done with gravity recombination according to the following principle:

- $F_{static+Spectral} = F_{static} + \sqrt{F_{RX}^2 + F_{RY}^2 + F_{RZ}^2}$
- $F_{static-Spectral} = F_{static} - \sqrt{F_{RX}^2 + F_{RY}^2 + F_{RZ}^2}$

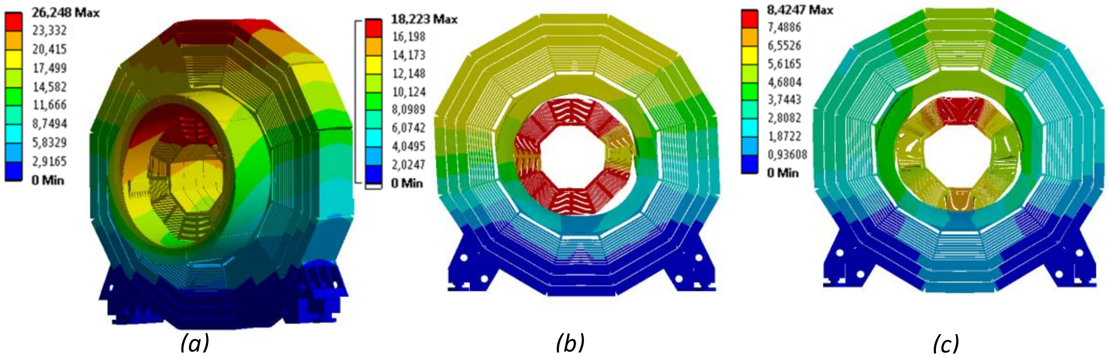


Figure 13: with recombination (a) results for acceleration parallel to the beam pipe; (b) results for acceleration perpendicular to the beam pipe; (c) results for vertical acceleration

Results from Figure 12 and Figure 13 are summarized in next tables

Table 2: Results for ECAL response without mass recombination

Without recombination	[1]Static case (own weight)	Acceleration along beam axis	Acceleration perpendicular to beam pipe	Acceleration vertical
Max displ	5.62	**24.88**	**17.25**	**2.84**
Gap❶	1.98	**2.29**	**1.89**	**2.05**
Gap❷	1	**0.98**	**0.98**	**0.98**

Table 3: Results for ECAL response with mass recombination

With recombination	Acceleration along beam axis	Acceleration perpendicular to beam pipe	Acceleration vertical
Max disp	**26.25**	**18.22**	**8.42**
Gap❶	**1.98**	**1.74**	**1.92**
Gap❷	**0.98**	**0.98**	**0.98**

On one hand, it is clearly seen that gap❷ along the beam axis is almost unaffected by the study cases provided that ECAL modules are not allowed to rail relatively to the HCAL after insertion. On the other hand, one can notice that even if detection layers are not taken into account yet, mass recombination affects mainly vertical motion as expected. Finally gap❶ as well as the full structure is the most affected by ground horizontal motion. Globally, the ECAL modules tend to follow general structure motion despite some gap❶ reduction.

5. Conclusions and prospective:

Along this report it has been shown that the ECAL barrel motion is linked to the surrounding elements and their designs. Among the two investigated HCAL designs, the AHCAL introduces the biggest deformations under static load. Using this conservative candidate for further investigation with seismic load revealed that simplifications and boundary conditions choices affect significantly the results. In any cases, first normal modes for this large and heavy structure are in peak range of japan earthquake spectrum. This dynamic component should be kept in mind for gap sizing especially in phi angle. Further investigations by introducing virtual masses and comparing with the SDHCAL design will help in getting a better understanding.

[1] Results extracted from case4 in section 4.2

References

[1] H. Videau and J. C. Brient, "A Si-W calorimeter for linear collider physics," in Proc. 10th International Conference on Calorimetry in High Energy Physics (CALOR 2002), Pasadena, California,
pp. 309–320.

[2] H. Videau and J. C. Brient, "Calorimetry optimised for jets," in Proc. 10th International Conference on Calorimetry in High Energy Physics (CALOR 2002), Pasadena, California.

[3] ILD Collaboration, T. Behnke et al., "International Linear Collider – Detector Baseline Document," tech. rep., DESY / FERMILAB / CERN, 2013. https://edmsdirect.desy.de/edmsdirect/file.jsp?edmsid=D00000001021295.

[4] M. Anduze, A. Bonnemaison, V. Boudry, and M. Frotin, "Utilisation de capteurs à réseaux de Bragg pour la mesure in-situ de déformée d'une structure alvéolaire élaborée en matériaux composite," in 7`eme Colloque Interdisciplinaire en Instrumentation. 2016.

[5] V. Balagura et al., "SiW ECAL for future e+e− collider," in Proceedings, International Conference on Instrumentation for Colliding Beam Physics (INSTR17): Novosibirsk, Russia. 2017. arXiv:1705.10838 [physics.ins-det]. http://inspirehep.net/record/1601898/files/arXiv:1705.10838.pdf.

[6] Eurocode 8: Seismic Design of Buildings.

[7] ISO 3010: International Standard Based for Design of Structures - Seismic Actions on Structures